

Global Trends and Hotspots in Ultrasound Imaging for Rehabilitation Research: A Bibliometric and Visualization Analysis

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Objective: As a non-invasive, convenient and real-time imaging tool, ultrasound has provided new imaging evidence for rehabilitation and scientific research in recent years. As the volume and scope of studies grow, analyzing the innovative applications and research trends of ultrasound in rehabilitation is essential. This study employs bibliometric methods to map global research collaboration networks in ultrasound for rehabilitation, explore research dynamics, and predict future research themes based on emerging trends.

Methods: We performed a bibliometric analysis of 8346 articles from the Web of Science (WoS) Core Collection (1990–2024) using CiteSpace and VOSviewer.

Results: A total of 8346 articles were included. Annual publication volumes have a surge in the past five years. Western countries dominate research output, while institutions in China are emerging as significant contributors. Levent Ozcakar and Paul W. Hodges lead in publication volume and citation impact, respectively. Musculoskeletal ultrasound, intelligent algorithms, and skill education are key citation clusters and emergent topics. High-frequency keywords include ultrasound examination, exercise and efficacy validation emerging recently.

Conclusion: Ongoing research is likely to continue focusing on the reliability of ultrasound for diagnosing various diseases, musculoskeletal quantification through novel ultrasound technologies in physical therapy, and ultrasound monitoring and biofeedback in respiratory and postpartum rehabilitation. Additionally, musculoskeletal examination evidence, real-time training monitoring, and systematic review evaluation are gaining increasing attention. These emerging areas may serve as guiding themes for future research, providing a foundation for continued innovation in the application of ultrasound in rehabilitation.

Keywords: rehabilitation, ultrasonography, bibliometric

Introduction

Assessment and diagnosis are integral to the rehabilitation process, serving as critical guides for clinicians to identify key disease features and design tailored rehabilitation plans. Advances in technology have continuously refined assessment methods in rehabilitation medicine, evolving from traditional clinical approaches—such as muscle strength testing, joint angle measurement, and manual palpation—to more quantitative tools, including standardized scales, motion analysis, and imaging diagnostics.¹ In recent years, ultrasound has emerged as a non-invasive, convenient, and real-time imaging modality, gaining widespread adoption across various medical fields and clinical settings.²

Rehabilitation medicine has increasingly explored and applied ultrasound imaging in diverse contexts. These include bedside ultrasound for critically ill patients with limited mobility during early or ultra-early rehabilitation,³ evaluation of lung ventilation and diaphragmatic motion in cardiopulmonary and respiratory rehabilitation,^{4,5} assessment of joints and soft tissues in musculoskeletal rehabilitation,^{6,7} precise ultrasound-guided interventions,⁸ validation of manual therapies,⁹

and provision of imaging evidence in rehabilitation research.^{10,11} The expanding role of ultrasound in rehabilitation practice and research enhances visualization and dynamic assessment of internal structures, enabling clinicians and researchers to better understand patients' conditions and support clinical decision-making and scientific inquiry.

Since the inaugural International Symposium on Rehabilitation Ultrasound Imaging (RUSI) in 2006, the use of ultrasound in basic, applied, and clinical rehabilitation research has gained broader recognition and standardization.¹² Scholars have increasingly acknowledged the value and potential of ultrasound in rehabilitation research.^{13,14} While reviews have summarized its applications in fields such as physical therapy² and cardiopulmonary rehabilitation,¹⁵ a comprehensive analysis of innovative applications and research trends in ultrasound for rehabilitation remains lacking.

To address this gap, a systematic synthesis and qualitative analysis of published studies are warranted to map the overall landscape, emerging trends, and research hotspots in this field. This study employs bibliometric methods to analyze existing publications and visualize research dynamics.^{16,17} Key analyses include temporal trends in research themes, high-frequency keywords across periods, pivotal citations marking turning points, and the latest topics and publication trends. By integrating multidimensional network data—spanning countries, institutions, journals, authors, and key citations—this study evaluates shifts in research focus and hotspots, offering predictions for future directions and priorities. The findings are reported as follows:

Materials and Methods

Data Retrieval Strategy

This study conducted a bibliometric analysis using the WoS Core Collection to facilitate citation tracking and journal classification.¹⁸ We performed a bibliometric analysis of 8346 articles from the WoS Collection (1990–2024) using CiteSpace and VOSviewer. The detailed search strategy and methods are provided in [Appendix Part 1](#).

Literature Screening and Data Extraction

To ensure the integrity of the annual data, the search Settings cover publications from the establishment of the database to December 2024. [Figure 1](#) illustrates the process of screening and extracting data from the retrieved literature. The original search included 8722 articles. Through the refinement of the WoS database, 11 retracted articles were excluded. Through the CiteSpace software, 0 duplicate records were excluded. Ultimately, 8346 articles were identified and included in the final bibliometric analysis. All the original data of the included literature were refined and extracted from the WoS Core Collection, and the complete records and cited literature were exported for analysis and rendering by VOSviewer and CiteSpace software.

Bibliometric Software and Analytical Methods

Data analysis, network construction, and visualization were performed using Microsoft Excel 2021, VOSviewer (version 1.6.20), CiteSpace (version 6.4.R1), Scimago Graphica (version 1.0.49), and Pajek 64.

Microsoft Excel 2021 was used to compile and visualize the annual publication counts and co-citation frequencies. VOSviewer's robust capacity for generating large-scale literature knowledge maps¹⁹ was employed to perform bibliographic coupling analysis, create node maps of publication outputs by country, and visualize global research collaboration networks using Scimago Graphica. The VOSviewer parameter Settings are as follows: the attraction in layout is 2 and the repulsion is 1. The resolution in the clustering is 1 and the Min cluster size is 20 (Special parameter Settings existing in some figures will be specifically explained in the figure caption). Additionally, heatmaps and cluster distributions of highly cited articles and high-frequency keywords were generated and analyzed, with clustering results optimized and stratified using Pajek 64.

CiteSpace's strength in mapping citation characteristics and trends based on large datasets²⁰ was leveraged to analyze author and research group characteristics, construct dual-map overlays of journals and citations, and generate timeline views of key citations and keyword bursts. Taking the modularity Q value and the weighted average contour S value as the clustering criteria, it is generally considered that the Q value greater than 0.4 and the S value close to 1 are acceptable. The CiteSpace parameter is set as follows: time slicing from 1977 Jan to 2024 Dec; g-index, k=25; Pruning:

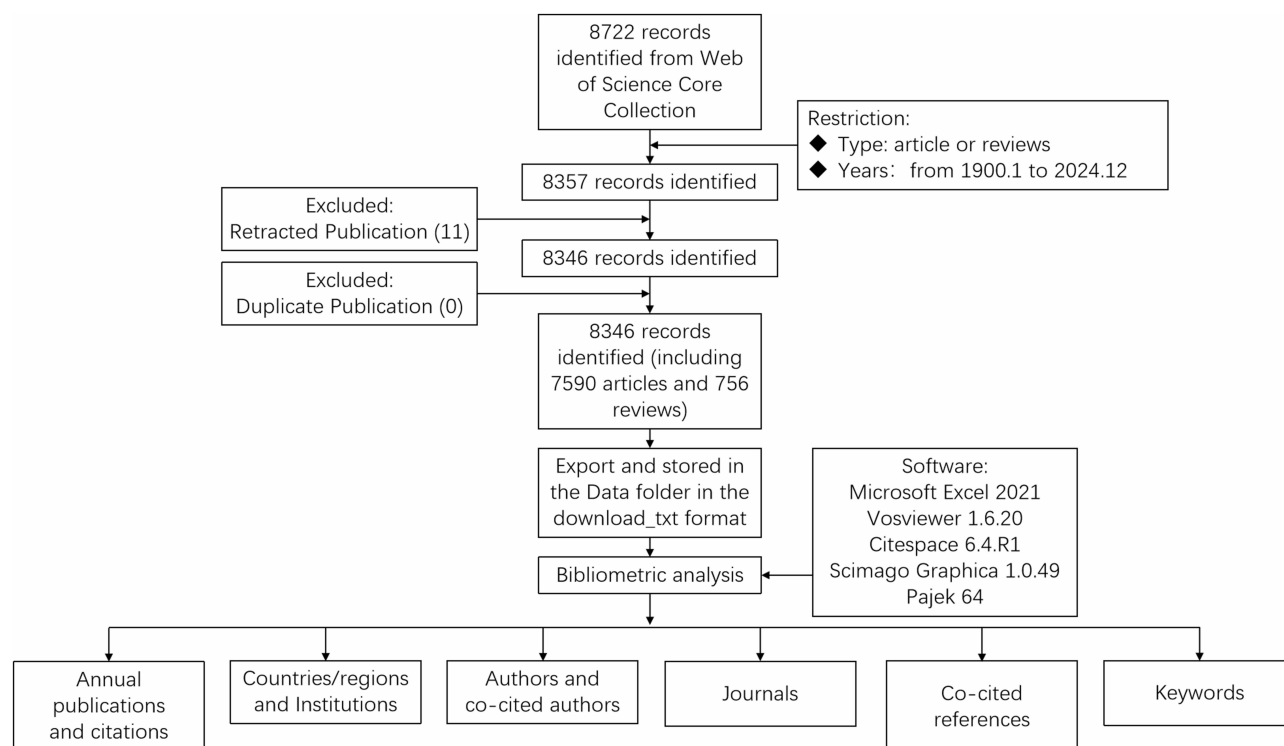


Figure 1 Detailed process for literature screening.

Pathfinder; excluded UNKNOWN (Special parameter Settings for some figures will be specifically explained in the figure caption).

Notably, this study focuses exclusively on ultrasound imaging and diagnostic techniques, not therapeutic ultrasound. Thus, the term “ultrasound” herein refers solely to “ultrasound imaging” or “ultrasound diagnostics”.

Equity, Diversity, and Inclusion Statement

The author group is gender balanced and consists of junior, mid-career and senior researchers from different disciplines, including seven researchers from China and one from Malaysia. We analyzed the literature on global ultrasound rehabilitation based on the WoS database, so there may be articles and research efforts that were not included in the database that were overlooked, and the research results may deviate from the actual research situation. Unfortunately, this study did not differentiate the effects of gender, race/ethnicity, or socioeconomic status. We will analyze the impact of the development of different economic and health forces on research and education in this field during the discussion.

Results

Quantitative Analysis of Annual Publications

The overall upward trend in research in this field saw a rapid increase in publications in 2020 and 2024, which may be related to factors such as the impact of Covid-19, the promotion of musculoskeletal ultrasound, and breakthroughs in intelligent image recognition technology.

A total of 8346 articles and reviews were included in this analysis. Based on WoS data, these publications garnered 175,974 non-self-citations, with an average of 22.77 citations per article and an H-index of 155, indicating substantial scale and impact in the field.²¹ Figure 2, derived from WoS data, illustrates trends in annual publication counts (Np) and co-citation frequencies (Nc), reflecting the overall development of the discipline. Research combining ultrasound and rehabilitation has achieved considerable scale, with growing attention to related studies and outputs. Notably, publication

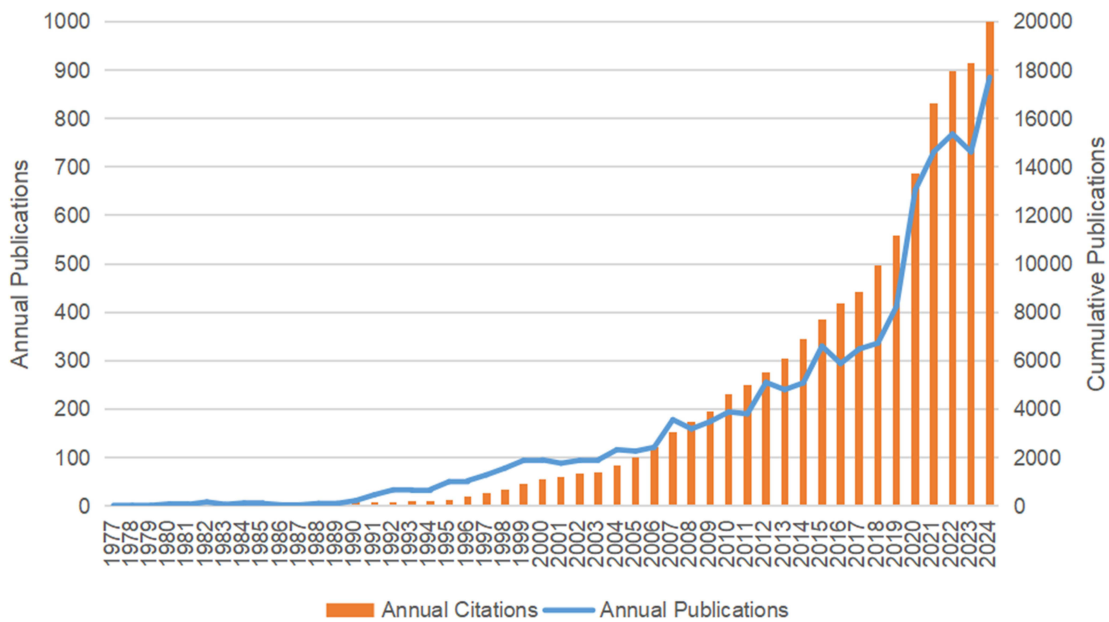


Figure 2 Articles related to the study of the application of ultrasound diagnosis in rehabilitation.

volumes surged in 2020 and 2024, suggesting the emergence of hotspot topics. A detailed periodization of the field’s development is provided in [Appendix Part 2](#).

Visualization Analysis of Global Research Forces (Countries, Institutions, Journals)

The United States is a global leader in research in this field, while countries like China and India have seen a rise in research investment and output in recent years.

Research integrating ultrasound with rehabilitation has been published by 123 countries. Table 1 summarizes publication data by country, while Figure 3 presents heatmaps, temporal maps, global research force map and collaboration networks. The United States leads in publication volume, citation frequency, H-index, and collaboration strength, demonstrating significant disciplinary leadership. Temporal maps reveal that countries such as Germany, the United States, and the United Kingdom initiated research early, achieving substantial scale and influence (high H-index). In contrast, countries like China and India have seen increased output since 2020, but their research impact and collaborative ties remain relatively weaker, indicating room for improvement in quality and partnerships.

Table 1 Top 10 Countries with the Highest Number of Published Studies

| Rank | Country | Publications | Total Citations | Average Citation | H-index | Total Link Strength |
|------|----------------|--------------|-----------------|------------------|---------|---------------------|
| 1 | USA | 2110 | 60,962 | 28.8919 | 111 | 1279 |
| 2 | China | 960 | 16,337 | 17.0177 | 60 | 416 |
| 3 | Germany | 680 | 16,187 | 23.8044 | 65 | 851 |
| 4 | United Kingdom | 676 | 24,187 | 35.7796 | 81 | 1077 |
| 5 | Italy | 583 | 18,006 | 30.8851 | 69 | 1036 |
| 6 | Japan | 554 | 12,768 | 23.0469 | 57 | 225 |
| 7 | Canada | 430 | 11,658 | 27.1116 | 59 | 463 |
| 8 | Australia | 411 | 13,766 | 33.4939 | 61 | 554 |
| 9 | Turkey | 386 | 5296 | 13.7202 | 34 | 210 |
| 10 | France | 352 | 11,732 | 33.3295 | 59 | 619 |

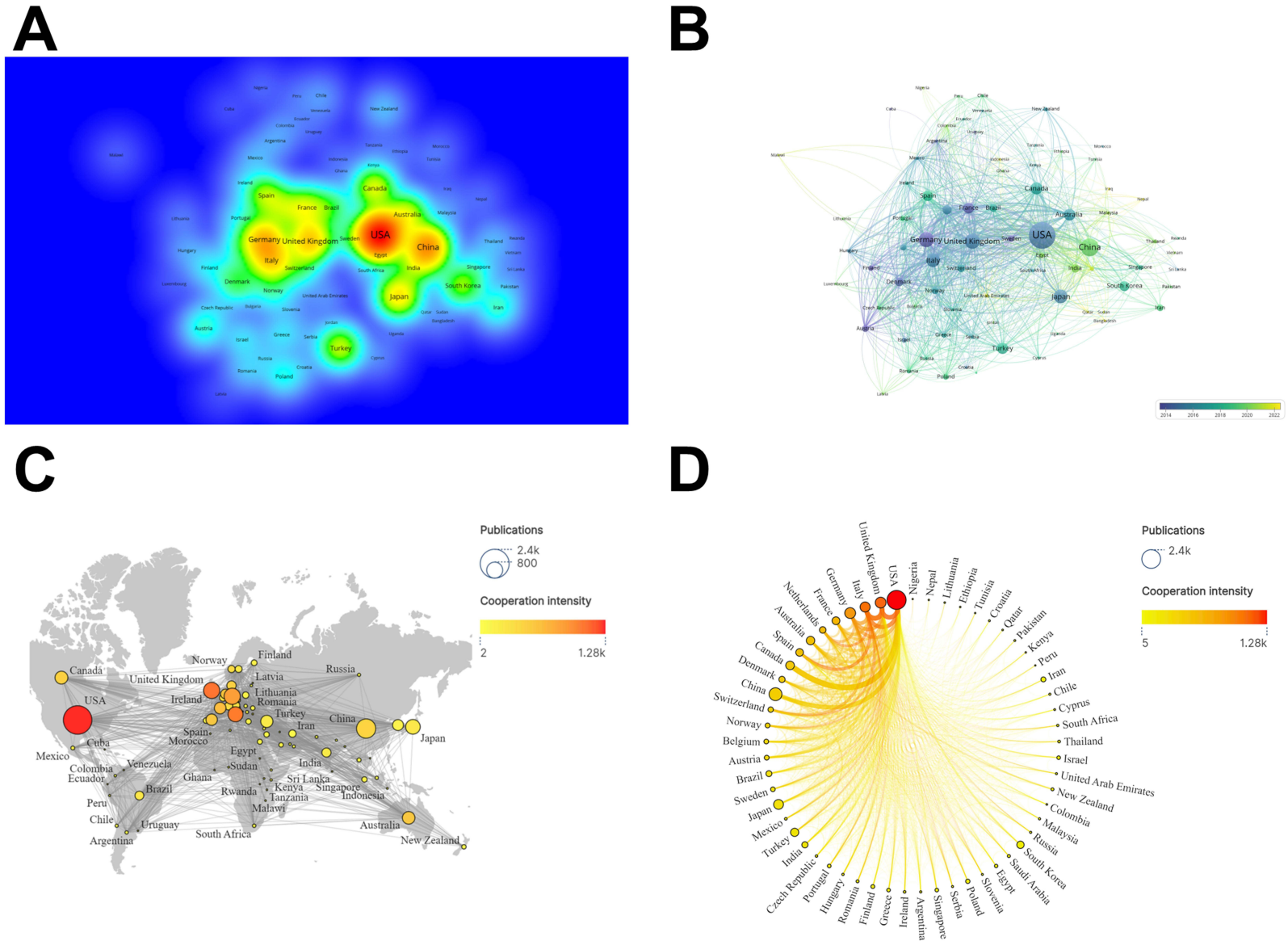


Figure 3 Contributions of different countries to the application of ultrasound in rehabilitation research. **(A)** Hotspot map of publications by countries, with the redder the color of a country's location indicating a higher number of published papers. **(B)** Time zone map of research intensity in the field of ultrasound rehabilitation by countries. The circles in the figure represent countries, and the lighter the color of a circle, the more recent the overall research publication time. The lines between the circles indicate collaborative relationships among countries. **(C)** World map of inter-country collaboration intensity, with larger dots indicating higher publication volumes and darker colors indicating stronger collaboration intensity. **(D)** Circular graph for evaluating international collaboration among clusters, with thicker links indicating closer cooperative relationships.

Table 2 Top 10 Institutions in the Number of Publications and Centrality Ranking

| Rank | Institutions | Count | Rank | Institutions | Centrality |
|------|---|-------|------|---------------------------------|------------|
| 1 | Harvard University | 132 | 1 | University of Copenhagen | 0.39 |
| 2 | University of California System | 119 | 2 | Sapienza University Rome | 0.32 |
| 3 | University of Copenhagen | 116 | 3 | University of Milan | 0.22 |
| 4 | Assistance Publique Hopitaux Paris | 101 | 4 | Columbia University | 0.16 |
| 5 | Institut National de la Sante et de la Recherche Medicale | 88 | 5 | Thomas Jefferson University | 0.15 |
| 6 | University of London | 87 | 6 | Monash University | 0.14 |
| 7 | Mayo Clinic | 71 | 7 | Eastern Virginia Medical School | 0.13 |
| 8 | University of Toronto | 70 | 8 | Medical University of Vienna | 0.12 |
| 9 | State University System of Florida | 69 | 9 | Baylor College of Medicine | 0.12 |
| 10 | University System of Ohio | 67 | 10 | King's College London | 0.12 |

Harvard University is the institution with the highest number of publications, while the University of Copenhagen has the highest centrality. Ultrasound-assisted muscle measurement and image recognition technology are important areas of focus for these institutions.

Using CiteSpace, we conducted a co-occurrence network analysis of research institutions to identify organizations with significant contributions. Table 2 lists the top 10 institutions by publication volume and centrality, while Figure 4 displays their network maps and emergent timeline plots of rapid publication growth. Harvard University leads in publication volume, with research spanning cardiopulmonary diagnostics,²² musculoskeletal measurements,^{23,24} ultrasound-guided interventions,²⁵ and intelligent algorithms.²⁶ The University of Copenhagen exhibits the highest centrality, particularly for studies on ultrasound-guided muscle training, which have garnered substantial attention.^{27,28} Emergent timeline analysis highlights that Chinese institutions (eg, Fudan University, Shanghai Jiao Tong University, and Sun Yat-sen University) have published extensively in the past five years, focusing on intelligent algorithms, deep learning networks, and ultrasound diagnostics.

The Journal of Ultrasound in Medicine has the highest number of publications, and methods from materials science and computer science are emerging in interdisciplinary research in ultrasound rehabilitation.

Table 3 summarizes data on the top 10 journals by publication volume, with Figure 5 showing journal co-occurrence networks, co-cited journal networks, and dual-map overlays. All top 10 journals are ranked in JCR Q1 or Q2, confirming

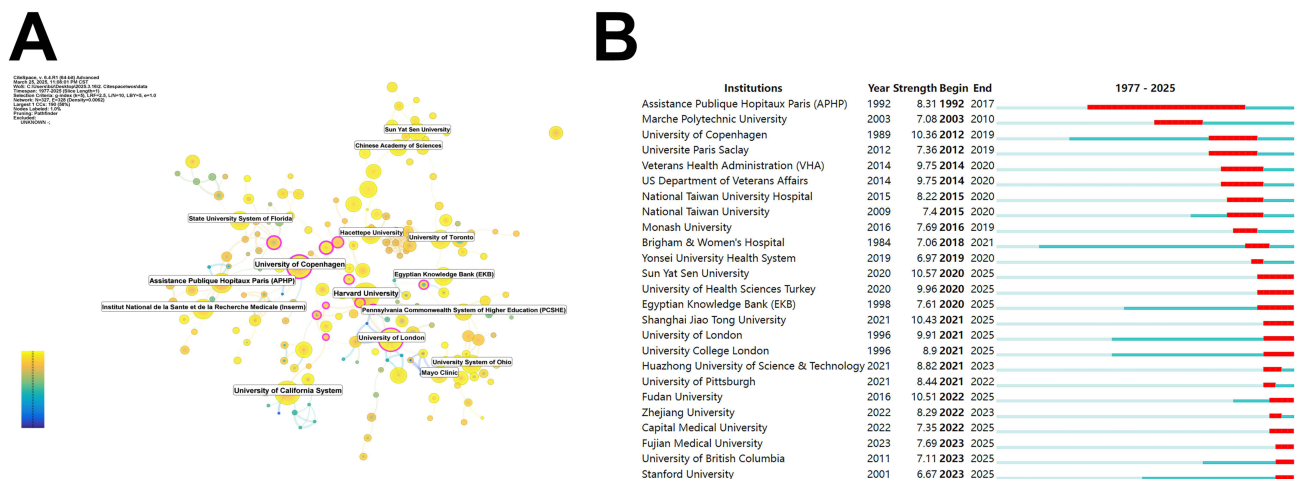


Figure 4 Visualizes the institutions conducting research related to the application of ultrasound diagnosis in rehabilitation. (A) Network diagram of research institutions engaged in ultrasound rehabilitation (g-index, k=5; Pruning: Pathfinder). The size of the nodes represents the number of published papers by the institutions, with larger nodes indicating more publications. Institutions with over 50 papers have labels. Links between nodes indicate collaboration between institutions, with darker link colors indicating earlier collaboration start times and thicker link lines indicating stronger collaboration. The purple outer ring of the circle represents centrality, with wider rings indicating higher centrality. Nodes with a centrality greater than 0.1 are indicated by purple rings, suggesting significant influence in the field. (B) Time zone map of the top 25 institutions with sudden increases in research volume, with the blue and red lines together forming the time axis, and the red part indicating the period of sudden growth.

Table 3 Top 10 Most Commonly Cited Journals

| Rank | Journal | Count | JCR Partitions | Rank | Journal | Centrality | JCR Partitions |
|------|--|-------|----------------|------|--|------------|----------------|
| 1 | Journal of Ultrasound in Medicine | 1727 | Q2 | 1 | Journal of the American College of Cardiology | 0.74 | Q1 |
| 2 | Radiology | 1614 | Q1 | 2 | Chest | 0.74 | Q1 |
| 3 | Ultrasound in Medicine and Biology | 1540 | Q2 | 3 | The Lancet | 0.63 | Q1 |
| 4 | New England Journal of Medicine | 1311 | Q1 | 4 | Radiology | 0.63 | Q1 |
| 5 | American Journal of Roentgenology | 1308 | Q1 | 5 | Circulation | 0.61 | Q1 |
| 6 | Lancet | 1194 | Q1 | 6 | American Review of Respiratory Disease | 0.59 | N/A |
| 7 | Journal of Applied Physiology | 1187 | Q1 | 7 | Journal of Thoracic and Cardiovascular Surgery | 0.57 | Q1 |
| 8 | PLOS One | 1051 | Q1 | 8 | Journal of Applied Physiology | 0.43 | Q1 |
| 9 | Medicine & Science in Sports & Exercise | 1014 | Q1 | 9 | European Journal of Applied Physiology | 0.41 | Q2 |
| 10 | Archives of Physical Medicine and Rehabilitation | 936 | Q1 | 10 | Stroke | 0.33 | Q1 |

the reliability of included publications and suggesting these journals as priority venues for researchers. CiteSpace's dual-map overlays illustrate disciplinary development, revealing frequent citations of medical and rehabilitation research in fields such as molecular biology, nursing, and kinesiology. Additionally, marginal areas of the overlays indicate contributions from materials science, physics, and computer science, underscoring the interdisciplinary nature of ultrasound in rehabilitation research.

Visualization Analysis of Global Research Hotspots

Key Authors and Co-Cited Authors

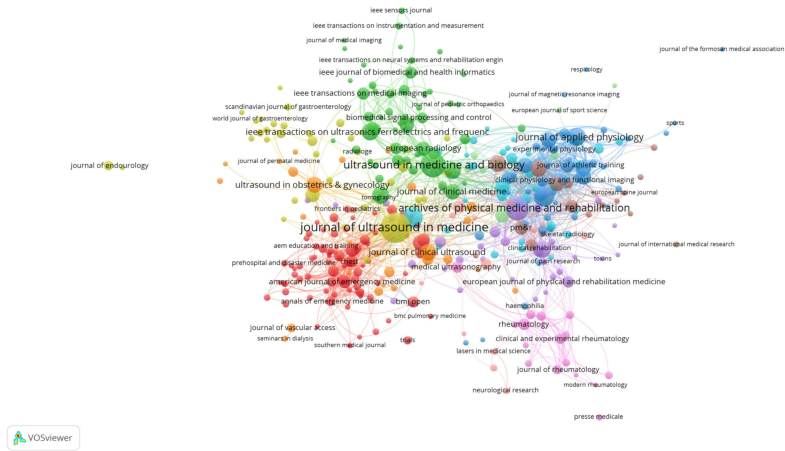
Ozcakar, Levent is the author with the most publications, Paul W. Hodges is the author with the highest citation impact, and the expansion and validation of musculoskeletal ultrasound methods are hot topics of common interest among researchers.

We analyzed the top 10 authors by publication volume and co-citation frequency (Table 4 and Table 5). Figure 6, generated via CiteSpace, visualizes the author collaboration network. It can be seen that the global high impact authors have formed different cooperative network groups. Levent Ozcakar leads in publication volume, with numerous articles on ultrasound imaging for clinical rehabilitation diagnostics, highlighting its utility in conditions such as fascial disorders and rotator cuff diseases.^{29–31} Hodges, Paul W., the most co-cited author, has used ultrasound and electromyography to investigate muscle activation, function, and displacement during various movements,^{32,33} providing foundational insights for clinical rehabilitation protocols and musculoskeletal ultrasound research. Magnusson, S. Peter is the highest co-citation author of centrality. His research on the reliability and movement changes of tendon structure detected by ultrasound has had an important impact in the academic community. These authors, pivotal nodes in the knowledge network, have made significant contributions across diverse applications of ultrasound in rehabilitation. Researchers are encouraged to follow their ongoing work.

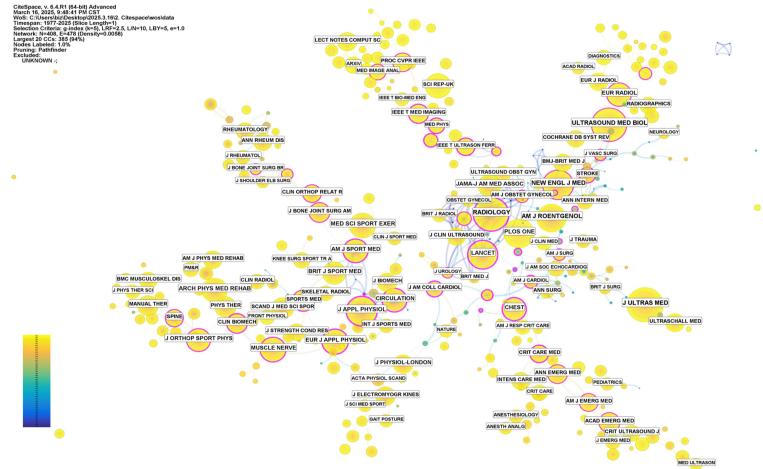
Co-Cited References

The co-citation and citation bursts of articles on topics such as Point-of-care ultrasonography and intelligent image recognition suggest important research directions in this field.

A



B



C

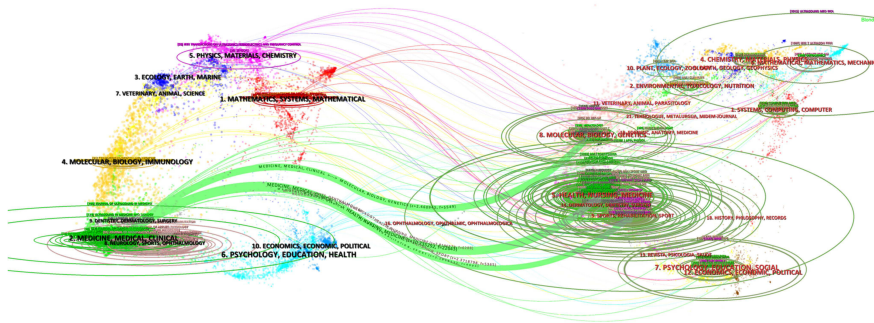


Figure 5 Visualization of source journals and co-cited journals related to rehabilitation ultrasound diagnosis. **(A)** Visualization map of source journals related to rehabilitation ultrasound diagnosis by VOSviewer. **(B)** Visualization of co-cited journals on rehabilitation ultrasound diagnosis by CiteSpace (g -index, $k=5$; Pruning: Pathfinder). Co-cited journals are represented by circles in the figure, and the co-citation relationships between journals are indicated by connecting lines. Journals with over 200 related articles have labels. **(C)** Superimposition of the double graphs of co-cited journals in rehabilitation ultrasound (The citing articles and their field keywords are displayed on the left, and the cited articles and their field keywords are displayed on the right). The colored curve paths in the middle represent the citation relationships. The stronger the connection, the wider the path). Ps: Due to the space limitations of the image in Figure 5, some journals use their abbreviations, such as J for Journal, SCI for science, MED for medicine, AM for American, BRIT for British, and PHYS for Physical. "R" stands for rehabilitation. For example, AM J SPORT MED refers to The American Journal of Sports Medicine.

Table 4 Top 10 Authors with the Most Publications

| Rank | Author | Institutions | Publications |
|------|---------------------|--|--------------|
| 1 | Ozcar, Levent | Hacettepe University | 35 |
| 2 | Fukunaga, Tetsuo | National Institute Fitness & Sports Kanoya | 19 |
| 3 | Naredo, Esperanza | Fundación Jiménez Díaz University Hospital | 16 |
| 4 | Chang, Ke-Vin | University of Auckland | 16 |
| 5 | Iagnocco, Annamaria | University of Turin | 15 |
| 6 | Kanehisa, Hiroaki | Ritsumeikan University | 14 |
| 7 | Picelli, Alessandro | University of Verona | 12 |
| 8 | Kara, Murat | Hacettepe University | 12 |
| 9 | Teyhen, Deydre S. | Def Hlth Agcy | 12 |
| 10 | Calvo-lobo, Cesar | Universidad Complutense de Madrid | 11 |

Table 5 Top 10 Most Commonly Co-Cited Authors

| Rank | Author | Institutions | Count |
|------|-------------------------|--|-------|
| 1 | Hodges, Paul W. | The University of Queensland | 254 |
| 2 | Moore, Christopher L. | Massachusetts Institute of Technology | 205 |
| 3 | Kubo, Keitaro | University of Tokyo | 186 |
| 4 | Volpicelli, Giovanni | Magna Graecia University of Catanzaro | 178 |
| 5 | Lichtenstein, Daniel A. | Universite Paris Saclay | 170 |
| 6 | He, Kangmin | Harvard Medical School | 167 |
| 7 | Ronneberger, Olaf | Google Incorporated & University of Freiburg | 167 |
| 8 | Cohen, Jeffrey H. | Ohio State University | 159 |
| 9 | Teyhen, Deydre S. | Def Hlth Agcy | 156 |
| 10 | Blaivas, Michael | University of South Carolina Columbia | 150 |

Co-cited references reflect the relational strength among cited works, with higher co-citation counts indicating foundational knowledge or innovative techniques. Table 6 lists the top five co-cited references, addressing bedside ultrasound,³⁴ medical image computing and computer-assisted interventions,³⁵ deep learning for image recognition,³⁶ consensus on lung ultrasound,³⁷ and reliability of ultrasound for muscle activity detection.³³ Using VOSviewer and CiteSpace, we generated co-citation networks (Figure 7A–C) and performed clustering via latent semantic indexing (LSI) in Figure 7, identifying key clusters in Figure 7D such as musculoskeletal ultrasound diagnostics (clusters 0, 2, 11, 14, 17), ultrasound technology (3, 5, 6), skill education (4, 7), and artificial intelligence integration (10, 11). The timeline in Figure 7E highlights recent attention to deep learning, bedside ultrasound, and muscle fat infiltration. Citation bursts, indicating shifts in research focus, were analyzed via CiteSpace, identifying 25 references with the strongest bursts (Figure 7F). The highest burst strength was observed for Liu SF et al's study on deep learning for medical ultrasound analysis.³⁸ Topics with bursts extending to 2025 include bedside ultrasound,^{39,40} muscle mass diagnostics,⁴¹ ultrasound education,⁴² and tumor detection.^{43,44}

High-Frequency Keyword Analysis

Keywords such as ultrasound diagnosis, ultrasound-assisted training, intelligent image recognition assistance, and effectiveness verification show significant influence in metrological analysis.

Using VOSviewer, we constructed a co-occurrence network of keywords to identify research hotspots and future trends. Table 7 lists the top 10 keywords by frequency. Figure 8 presents timeline plots, cluster maps, keyword co-occurrence networks, and burst analysis. Keywords form six color-coded clusters, categorized into four domains: clinical ultrasound practice (red, green), ultrasound technology algorithms (blue), musculoskeletal ultrasound diagnostics (yellow, purple), and ultrasound evidence in rehabilitation research (cyan). The keyword burst timeline reveals that pre-2000 research focused on disease screening. From 2001 to 2020, musculoskeletal and bedside ultrasound advancements

Table 6 Top 5 Most-Cited References in Literature

| First Author | Journal | Year | Citations | TLS |
|-----------------------|--|------|-----------|------|
| Moore, Christopher L. | The New England Journal of Medicine | 2011 | 175 | 1055 |
| Ronneberger, Olaf | Lecture Notes in Computer Science | 2015 | 169 | 498 |
| He, Kangmin | IEEE Conference on Computer Vision and Pattern Recognition | 2016 | 133 | 542 |
| Volpicelli, Giovanni | Intensive Care Medicine | 2012 | 127 | 949 |
| Hodges, Paul W. | Muscle & Nerve | 2003 | 125 | 1146 |

provided critical imaging evidence for muscle atrophy, regeneration, and training studies, while cardiopulmonary rehabilitation gained prominence during the COVID-19 pandemic, likely contributing to the publication surge around 2020. Since 2021, machine learning and AI-assisted imaging analysis, alongside validation of ultrasound diagnostics, interventions, and training, have emerged as prominent topics, potentially driving the publication spike around 2024. High-burst topics in the past five years suggest these areas are current hotspots for researchers and clinicians.

Discussion

Evolution of Research Hotspots in Ultrasound Imaging for Rehabilitation Assessment and Diagnosis

Advancements in ultrasound technology have shifted its applications in rehabilitation from basic visceral and cardiovascular diagnostics to assessments of blood flow dynamics^{45,46} and musculoskeletal structures.^{11,47} Portable ultrasound has become a vital tool for rehabilitation professionals, offering advantages over computed tomography (CT) and magnetic resonance imaging (MRI) in terms of cost, ease of use, and safety.

Initially employed in medical fields for visceral organ evaluation and internal disease diagnostics,^{48,49} ultrasound has evolved to address rehabilitation-specific needs. Early applications included real-time blood flow monitoring for cardiac function in exercise studies,⁵⁰ muscle mass assessment in bedridden patients, and detection of deep vein thrombosis,⁵¹ significantly enhancing disease evaluation and rehabilitation management. More recently, ultrasound assessment of lung and diaphragmatic function has emerged as a hotspot in respiratory rehabilitation,^{4,15} notably contributing to COVID-19 diagnostics and research.

Beyond these, ultrasound has been increasingly applied to musculoskeletal diagnostics, a domain where physical therapists excel. Early limitations restricted therapists to measuring muscle length, thickness, cross-sectional area, and contraction displacement^{52,53} for applications like sports injury risk assessment⁵⁴ and pelvic floor muscle function evaluation.^{55,56} With the advent of advanced techniques like ultrasound elastography,⁵⁷ modern musculoskeletal ultrasound enables detailed assessment of muscle structural changes and biomechanical properties. This approach is now widely used to diagnose conditions such as joint surface pathology, muscle, tendon, ligament, bursa, vascular, and nerve disorders.^{24,58–60} As an economical, safe, rapid, and real-time method, it supports the management of common rehabilitation conditions, including tendinopathies,⁶¹ fasciitis,⁶² joint effusions,⁶³ ligament injuries,⁶⁴ nerve entrapment,⁶⁵ impingement syndromes,⁶⁶ postpartum rectus diastasis,⁶⁷ and diaphragmatic assessment for respiratory training.⁶⁸ Ultrasound is poised to complement manual assessments, providing therapists with detailed, real-time imaging data. Concurrently, the integration of artificial intelligence (AI) and deep learning necessitates further validation of intelligent diagnostic and image-processing algorithms to ensure clinical reliability.

Research Trends in Ultrasound-Guided Rehabilitation Therapies

Ultrasound's role in facilitating visualization, biofeedback, and deep learning-based image recognition during rehabilitation therapies represents the most frequently cited and emergent research topics. Validating the accuracy of these methods and their therapeutic efficacy remains a critical focus for future studies.

As ultrasound applications in rehabilitation deepen, its visualization capabilities span the entire treatment process—from pre-treatment diagnostics to intraoperative guidance and post-treatment evaluation—offering clinicians richer data.

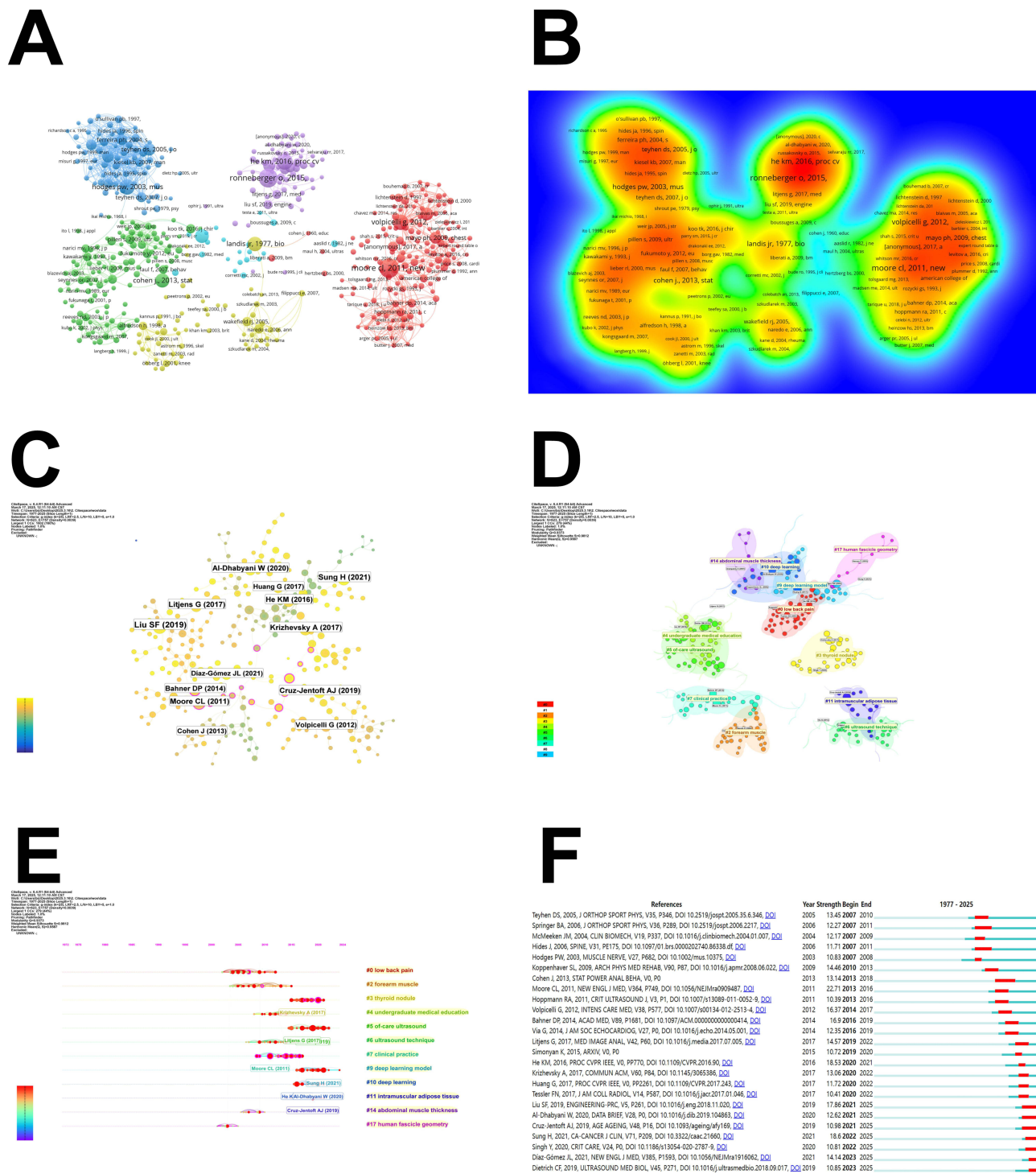


Figure 7 Visualization of co-cited references on the use of ultrasound diagnosis in rehabilitation. **(A)** Network of reference nodes co-cited by VOSviewer. Circles represent co-cited literature, and nodes of the same color indicate that their research topics have certain similarities. **(B)** Density visualization of co-cited references, the redder the regional color indicates the higher the citation intensity. **(C)** CiteSpace visualization of co-cited reference node network, the darker the color and the earlier the time. **(D)** Cluster analysis of co-cited references based on LLR algorithm, cluster areas and labels of different colors are formed. The value of cluster number indicates the intensity of attention to cluster topics within the discipline. The smaller the cluster value, the closer the relationship with the topic and the higher the attention. **(E)** The time line arrangement diagram of different clustering topics. **(F)** The time zone diagram of the top 25 references in terms of the emergent intensity of citations. Ps: Figure 7A labels adopt the abbreviation format of the citation, that is, the author's abbreviation plus the year of the article plus the included journal. For example, moore cl, 2011, new refers to Moore, Christopher L. 2011, The New England Journal of Medicine.

Table 7 Top 10 Keywords with the Highest Frequency

| Rank | Keywords | Occurrences | TLS |
|------|-----------------|-------------|--------|
| 1 | Ultrasonography | 2500 | 12,216 |
| 2 | Ultrasound | 1811 | 8767 |
| 3 | Diagnosis | 809 | 3980 |
| 4 | Sonography | 685 | 3448 |
| 5 | Exercise | 621 | 3419 |
| 6 | Management | 516 | 2454 |
| 7 | Reliability | 421 | 2626 |
| 8 | Rehabilitation | 362 | 1985 |
| 9 | Strength | 334 | 2218 |
| 10 | Education | 315 | 1566 |

Ultrasound-guided therapies include acupuncture validated by ultrasound,^{69,70} ultrasound-targeted shockwave therapy,⁷¹ and ultrasound-guided platelet-rich plasma injections,^{72,73} enabling precise, efficient, and safe lesion targeting. Additionally, ultrasound-guided biofeedback training⁷⁴ and AI-assisted approaches⁷⁵ have garnered attention, though robust clinical evidence remains limited. These areas are likely to drive future research.

Trends in Ultrasound Technology for Rehabilitation Vocational Education

While ultrasound technology has significantly advanced modern rehabilitation diagnostics and research, disparities in its application across countries highlight the need for standardized post-professional education.

Despite growing evidence of ultrasound's utility in rehabilitation, training for its use among rehabilitation professionals often lacks professional oversight, standardized curricula, and regulatory frameworks. In the United States, therapist organizations have established training guidelines since around 2018,^{2,76} but standardized training for rehabilitation professionals in regions like China remains in its infancy. Future efforts should aim to promote more standardized, professional, and widespread integration of ultrasound in clinical rehabilitation. A brief quality report about the individual articles introduced and analyzed in the article is provided in [Appendix Part 3](#).

To further align the bibliometric analysis results with the latest research developments in the field, we conducted a targeted search and summarization of high-quality new studies in rehabilitation ultrasound over the past year, building on the original search strategy. The findings primarily focused on the following aspects.

First, ultrasound imaging has been employed as robust imaging evidence in various novel treatment and evaluation protocols. For example, Jakub Katolický et al utilized ultrasound assessment combined with novel analysis software to achieve quantitative evaluation of the organization and density of collagen bundles within the tendon, thereby assessing the positive effects of extracorporeal shockwave therapy (ESWT) on the structure of patellar tendinopathy (IF 10.1, Q1);⁷⁷ Chao Yang et al evaluated the clinical efficacy of percussion massage therapy for chronic nonspecific low back pain by measuring fascial echo intensity and thickness via ultrasound (IF 3.4, Q1).⁷⁸ Additionally, numerous high-quality studies have emerged to validate and compare existing rehabilitation methods under new evidence and to guide optimal therapies. For instance, Scott K Crawford et al used ultrasound to compare the structure and morphology of the hamstrings following interventions with eccentric Romanian deadlifts or Nordic hamstring exercises, demonstrating high consistency in effects between the two protocols;⁷⁹ Shu-Mei Yang et al investigated changes in ultrasound-derived muscle characteristics in post-stroke patients with ankle spasticity under different ESWT doses, showing that increasing the ESWT dose may enhance muscle structure and function in stroke rehabilitation (IF 5.2, Q1).⁸⁰ Overall, in recent years, researchers have leveraged ultrasound methods to quantify data on tissue structural thickness⁸¹/length/angle,⁷⁹ contraction status,⁸² local perfusion,⁸³ and mechanical properties under stress,⁸⁴ thereby providing compelling evidence for the efficacy and mechanisms of various rehabilitation approaches.

On the other hand, with advancements in the precision of ultrasound examinations and the expansion of their applications, the integration of ultrasound into implementation recommendations and evidence-based guidelines for

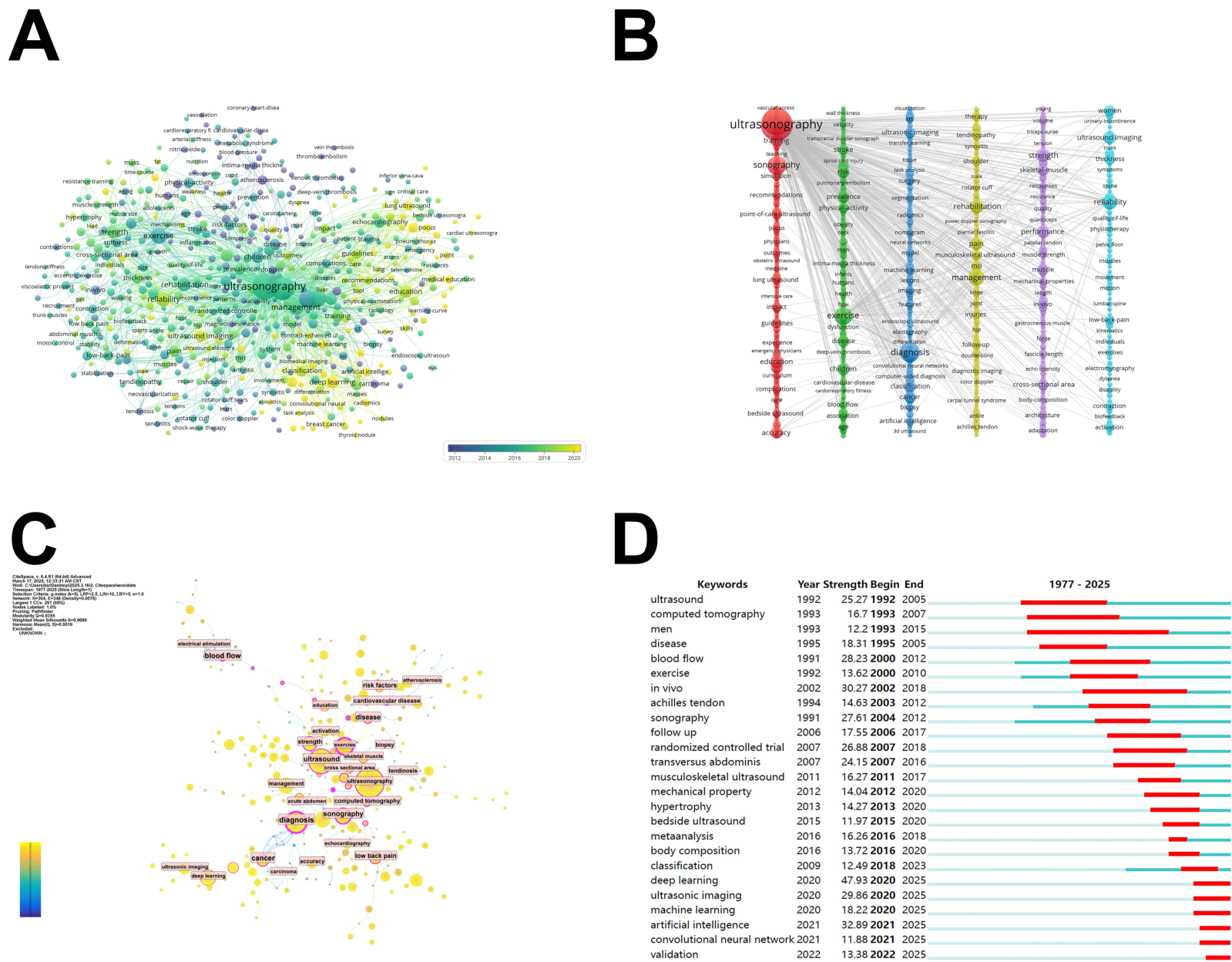


Figure 8 Keyword visualization for research related to ultrasound rehabilitation. **(A)** Keyword time network diagram visualized by VOSviewer. The larger the circle, the higher the frequency of occurrence; The darker the color, the earlier it appears; The thicker the line, the stronger the correlation between the two topics. **(B)** High-frequency keyword clustering chart. **(C)** The keyword network diagram drawn by CiteSpace is divided into 6 clusters according to different colors (g-index, k=5; Pruning: Pathfinder). Nodes with centrality greater than 0.1 are represented by purple rings, indicating that this keyword has an important influence in the field. **(D)** The time zone diagram of the top 25 keywords with the strongest occurrence frequency (explosive growth in a certain period), and the blue line and red line together constitute the time axis. The red part is the time period in which it erupted.

common diseases in rehabilitation medicine has increased. For example, the latest article published by Daniel M Cushman team on the feasibility of ultrasound as a predictive indicator for patellar tendon, Achilles tendon, and plantar fascia injuries in university athletes points out that areas showing abnormalities on ultrasound scans can more accurately predict future injuries compared to areas where patients self-report a history of old injuries (IF 16.2, Q1).⁸⁵ Furthermore, clinical ultrasound implementation recommendations for conditions such as shoulder joint lesions,^{86,87} carpal tunnel syndrome,⁸⁸ trigger finger,⁸⁹ Achilles tendinopathy,⁹⁰ plantar fasciitis,⁹¹ and nerve entrapment⁹² are gradually being refined, with increased tracking and reporting on the education and teaching of corresponding techniques.⁹³

Finally, breakthroughs in hardware for novel ultrasound technologies and upgrades in analysis systems have also yielded research updates on the presentation and interpretation of high-resolution ultrasound images,^{94,95} as well as intelligent recognition and information optimization in the context of artificial intelligence.⁹⁶

Strengths and Limitations

This study relies solely on publications from the Web of Science Core Collection, potentially excluding key studies from other databases and introducing bias relative to real-world research. To ensure citation data integrity, studies on internal medicine ultrasound diagnostics and technical algorithms may have been disproportionately weighted, while recent publications may not yet have garnered sufficient attention or citation bursts, potentially skewing results. As a bibliometric analysis, this study's findings may diverge from current research realities, necessitating integration with real-world studies for further qualitative synthesis alongside quantitative data.

Conclusion

This bibliometric analysis of ultrasound in rehabilitation reveals a steadily expanding research field, with explosive growth in the past five years. Western countries, particularly the United States, dominate global research output, while certain Chinese institutions have shown rapid increases in contributions. Bridging studies include bedside ultrasound, medical imaging algorithms, deep learning-based image recognition, lung ultrasound consensus, and reliability of ultrasound for muscle activity detection. Over the past five years, deep learning and AI-assisted imaging analysis, alongside validation of ultrasound diagnostics, interventions, and training, have emerged as prominent topics. These trends suggest future hotspots may include reliability studies of intelligent ultrasound imaging for diverse disease diagnostics, quantitative musculoskeletal analysis using novel ultrasound techniques, and ultrasound monitoring and biofeedback in respiratory and pelvic rehabilitation.

In summary, this study provides valuable insights into the current state and trends of ultrasound imaging and diagnostics in rehabilitation, offering a reference for scholars and suggesting directions for future research.

Abbreviations

SCI, Science Citation Index; SCIE, the Science Citation Index Expanded; SSCI, Social Sciences Citation Index; ESCI, Emerging Sources Citation Index; LLR, Log-Likelihood Ratio; WOS, Web of Science; Np, the number of publications; Nc, the number of annual co-citations; JCR, Journal Citation Reports; RUSI, rehabilitation ultrasound imaging; TLS, Total Link Strength; ESWT, extracorporeal shockwave therapy.

Consent for Publication

We confirm that we can release detailed information of any images, videos, audio recordings, etc., and have shown the content of the article to be published to the consenters.

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Disclosure

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